Adaptive Beamforming for MIMO Space-Time Block Coding over Fast Fading Channel

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Abstract

This paper describes a novel Multiple-Input Multiple-Output (MIMO) system robust to fast fading environment. Space time block coding (STBC) using two transmit antennas is employed at the mobile station while the base station allows implementation of adaptive array using recursive least squares (RLS) algorithms to overcome fast fading problem. The proposed scheme adopts simultaneous transmission of data and pilot signals reducing control errors occurred by delay of obtaining Channel State Information (CSI). The simulation results show that the proposed scheme can defeat Doppler spread in higher frequencies and suppress co-channel interference up to $N-1$ users with using N receiving antennas.

1. Introduction

Multiple-Input Multiple-Output (MIMO) promises huge capacity increases. The average channel capacity of such a system is approximately proportional to the number of array elements. A different way to use multiple transmit antennas is to realize transmit diversity. The most effective method for this aim is space-time block coding (STBC) such as Alamouti's [1]. STBC in fading effects due to multipath time delay spread has been studied extensively in many publications. However, the study of STBC in fading effects due to Doppler-spread has not yet sufficiently investigated. In order to overcome signal degradation caused by Doppler spread for high-speed moving vehicle at higher frequencies, a scheme is needed to improve signal distortion caused by moving mobile station. A novel adaptive beamforming for STBC in [1] is initially introduced for multi-user and quasi-static channel. And now, we are interesting STBC in fast fading condition by introducing a new transmission scheme with adaptive beamforming based on the method in [2]. In the proposed scheme, the pilot signal and information on data are transmitted concurrently. Moreover, the beamforming using Recursive Least squares (RLS) algorithms in [3], [4] is adopted for the continuous tracking of fading environment.

2. Doppler Spread Effects

The propagation of radio signal is affected by various physical factors. In this section we review Doppler spread and how it becomes a serious problem for mobile communications. Signal is transmitted from high speed Mobile Stations (MSs) each of which consists of two antenna elements, and is received by adaptive array with four antenna elements at the base station. From Fig. 1, it is obviously seen that a motion of mobile station results in an apparent spread in frequency which depends on angular distribution of multipath waves. The degree of Doppler spread is expressed by the maximum Doppler shift f_D which is given by v/λ (v : velocity of MS, λ : wavelength of radio signal).

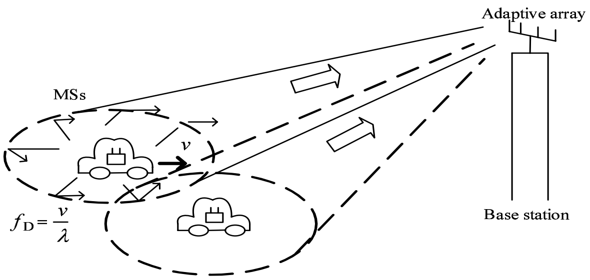


Fig. 1: MIMO system for multi-user mobile communication

Figure 2 illustrates a widely-used diagram of conventional transmission sequence for Adaptive Array (AA). In each period of frame T_f includes pilot period T_p and data period T_d while symbol duration is assumed to be T_s. Now we consider fast fading index β_0 as a measure of Doppler Effect. This index is given by

$$\beta_o = f_D T_s \tag{1}$$

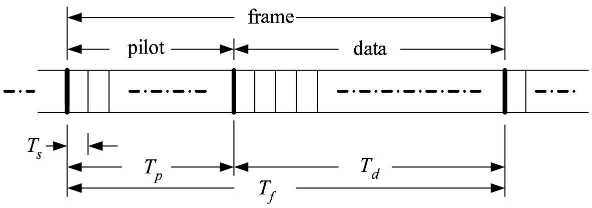


Fig. 2: Conventional transmission signal sequence for adaptive array system

Generally, a fading channel index value $\beta_0 \geq 0.01$ in a system is classify the system as a fast fading channel. On the other hand, transmission signal sequence of adaptive array shown in Fig. 2 is necessary to keep a quasi-stationary condition described as

TABLE 1: FAST FADING INDEX β_0/β_{AA} FOR $v = 30m/s$ (OR $108km/h$)

f / T_s	2 GHz	5 GHz
1 μsec	0.0002/0.02	0.0005/0.05
10 μsec	0.002/0.2	0.005/0.5
100 μsec	0.02/2	0.05/5

___ : $\beta_0, \beta_{AA} > 0.01$

$$\beta_{AA} \equiv f_D(T_p + T_d) = f_D T_f \ll 1 \tag{2}$$

It is commonly set $\beta_{AA} \leq 0.01$ to avoid fast fading effect. Assuming that the vehicular velocity is 30 m/s (108 km/h) and T_f is $100T_s$, β_0 and β_{AA} can be estimated as shown in Table 1. As can be noticed from this table, fast fading condition shown by underline appears easily.

3. MIMO STBC Adaptive Array

MIMO STBC Adaptive Array scheme has been considered as a countermeasure for fast fading environment. Since delay of obtaining channel state information (CSI) causes significant control error of adaptive array in fast fading environment. Obtaining CSI without delay is essential for the control. We adopt simultaneous transmission of data and pilot signals through different antennas. The concept of this method is clarified in Fig. 3

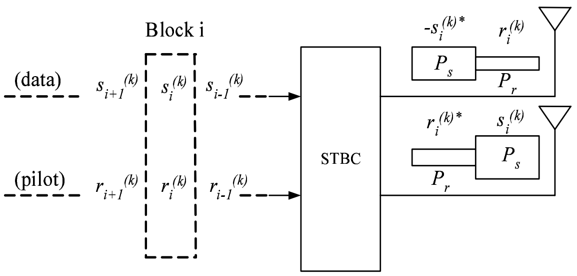


Fig. 3: Proposed transmitting method

Concerning Block i for user k, data signal $s_i^{(k)}$ and pilot signal $r_i^{(k)}$ are transmitted at the same time. For the convenience of following discussions, let us define transmission power sharing between pilot signal and data signal as follows

$$P_r^{(k)} = < |r_i^{(k)}|^2 > \tag{3}$$

$$P_s^{(k)} = < |s_i^{(k)}|^2 > \tag{4}$$

$$\xi^{(k)} = \frac{P_s^{(k)}}{P_s^{(k)} + P_r^{(k)}} \; ; \; P_r^{(k)} + P_s^{(k)} = const. \tag{5}$$

Where $< \, . \, >$ denotes ensemble average. In this paper, we will determine the value of power efficiency $\xi^{(k)}$ for all MSs later. The proposed MIMO scheme employs STBC with AA at the base station as shown in Fig. 4. At transmission side, kth user at time t sends two symbols, pilot signal $r_i^{(k)}$ over its 1st antenna and transmission data $s_i^{(k)}$ over its 2nd transmit antenna. At the next symbol time, time $(t+T_s)$, where T_s is a symbol duration, antenna 1 transmits $-(s_i^{(k)})^*$ while antenna 2 transmits $(r_i^{(k)})^*$ where $(.)^*$ indicates the complex conjugate.

On the other hand, the base station consists of reception processing and adaptive beamforming. In each receive antenna unit, the reception processing separates symbol into two streams namely odd stream (indexed as 1) included symbol transmitted at time t and even stream (indexed as 2) included symbol transmitted at time $t + T_s$. Note that it is necessary to take complex conjugate on the even stream, since all symbols transmitted at time $t + T_s$ are complex conjugated. After reception processing containing AWGN and other user signals, the signals from transmitted Block i in the nth receive antenna are given by

$$x_{n1}(i) = \sum_{k=1}^{K} [s_i^{(k)} h_{n1}^{(k)} + r_i^{(k)} h_{n2}^{(k)}] + n_{n1} \tag{6}$$

and

$$x_{n2}(i) = \sum_{k=1}^{K} [-(r_i^{(k)})^* h_{n1}^{(k)} + (s_i^{(k)})^* h_{n2}^{(k)}] + n_{n2} \tag{7}$$

Denote

$$\boldsymbol{x}_n(i) = \begin{bmatrix} x_{n1}(i) & x_{n2}^*(i) \end{bmatrix}^T \tag{8}$$

and define reception signal vector for Block i transmitted signal as

$$\boldsymbol{x}(i) = \begin{bmatrix} (\boldsymbol{x}_1(i))^T & (\boldsymbol{x}_2(i))^T & \ldots & (\boldsymbol{x}_N(i))^T \end{bmatrix}^T \tag{9}$$

where $(.)^T$ indicates vector transpose. The reception signal vector $\boldsymbol{x}(i)$ and $[2N \times 1]$ weight vector $\boldsymbol{w}_1^{(k)}$ are then combined to produce estimated pilot output $\tilde{r}_i^{(k)}$ and data output $\tilde{s}_i^{(k)}$. They are given by

$$\boldsymbol{w}_1^{(k)} = \begin{bmatrix} w_{11}^{(k)} & w_{12}^{(k)} & \ldots & w_{N1}^{(k)} & w_{N2}^{(k)} \end{bmatrix}^T \tag{10}$$

$$\tilde{r}_i^{(k)} = (\boldsymbol{w}_1^{(k)})^H \boldsymbol{x}(i) \tag{11}$$

$$\tilde{s}_i^{(k)} = (\boldsymbol{w}_2^{(k)})^H \boldsymbol{x}(i) \tag{12}$$

where $(.)^H$ is the complex conjugate transpose. The weight vector $\boldsymbol{w}_2^{(k)}$ is determined from weight vector $\boldsymbol{w}_1^{(k)}$ as

$$\boldsymbol{w}_2^{(k)} = \begin{bmatrix} (w_{12}^{(k)})^* & -(w_{11}^{(k)})^* & \ldots & (w_{N2}^{(k)})^* & -(w_{N1}^{(k)})^* \end{bmatrix}^T \tag{13}$$

The optimal weights are chosen to minimize the mean-square error (MSE) between beamformer output and the reference signal such that

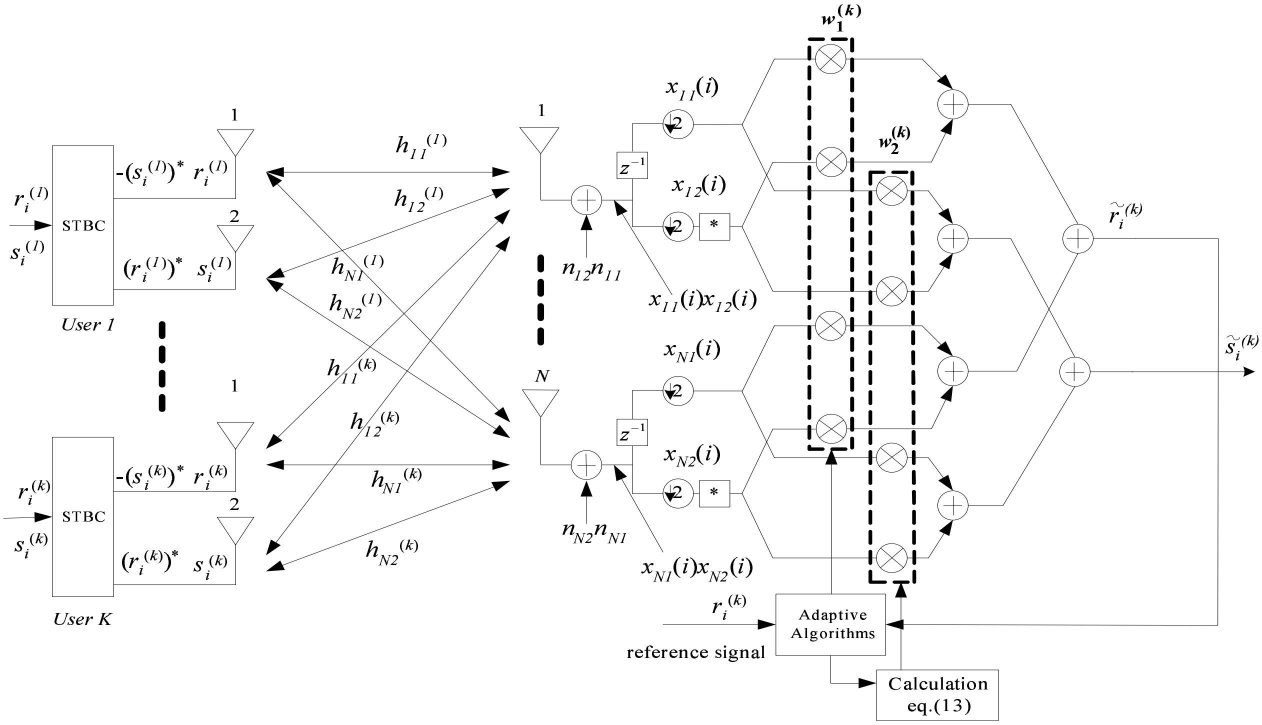


Fig. 4: Adaptive Beamforming configuration for multiuser STBC (STE:Space Time Encoding)

$$\boldsymbol{w}^{(k)}_{1_{opt}} = \arg\min < |r^{(k)}_i - (\boldsymbol{w}^{(k)}_i)^H \boldsymbol{x}(i)|^2 > \quad (14)$$

The optimal weight $\boldsymbol{w}^{(k)}_{1_{opt}}(i)$ is time-variant and referred to optimum Wiener solution

$$\boldsymbol{w}^{(k)}_1(i) = \boldsymbol{R}^{-1}(i)\boldsymbol{b}^{(k)}(i) \quad (15)$$

$$\boldsymbol{R}(i) = \gamma \boldsymbol{R}(i-1) + \boldsymbol{x}(i)\boldsymbol{x}^H(i) \quad (16)$$

$$\boldsymbol{b}^{(k)}(i) = \gamma \boldsymbol{b}^{(k)}(i-1) + (r^{(k)}_i)^* \boldsymbol{x}(i) \quad (17)$$

In this paper, we adopt Recursive Least Squares algorithm (RLS) to obtain weight vector $w^{(k)}_1$. The forgetting factor $0 < \gamma < 1$ is a parameter of the RLS algorithms, and is intend to follow temporal variation of CSI.

I.i.d. Rayleigh fading, which has the spectrum of Jakes model [5], is considered in this system. This model is characterized by Doppler spread f_D and uniformly distributed multipath direction around moving mobile station. The time varying channel characteristic $H^{(k)}(t)$ for user k can be written in matrix form as.

$$H^{(k)}(t) = \begin{bmatrix} h^{(k)}_{1,1}(t) & h^{(k)}_{1,2}(t) \\ \vdots & \vdots \\ h^{(k)}_{N,1}(t) & h^{(k)}_{N,2}(t) \end{bmatrix} \quad (18)$$

Denote the channel amplitude between a transmit antenna m of user k and a receive antenna n is a complex number $h^{(k)}_{n,m}(t)$ $(m = 1, 2; n = 1, \ldots, N)$ and average channel power gain is set to 1 as follows

$$< |h^{(k)}_{11}|^2 > = < |h^{(k)}_{12}|^2 > = \ldots = < |h^{(k)}_{N2}|^2 > = 1 \quad (19)$$

Data signal power $P^{(k)}_s$ and pilot signal power $P^{(k)}_r$ are computed as in equation (3) and (4), respectively. Summation of both power is called total power $P^{(k)}_t$

$$P^{(k)}_t = P^{(k)}_s + P^{(k)}_r \quad (20)$$

Noise signals shown in Eqs. (6) and (7) can be explained in average power gain as follows

$$P_n = < |n_{11}|^2 > = < |n_{12}|^2 > = \ldots = < |n_{N2}|^2 > \quad (21)$$

The ratio of noise power P_n and total power $P^{(k)}_t$ intends to show $CNR^{(k)}$ calculation for the system as follows:

$$CNR^{(k)} = \frac{P^{(k)}_t}{P_n} \quad (22)$$

In this paper, we assume that all of $CNR^{(k)}$ have the same value for k and simply denoted by CNR.

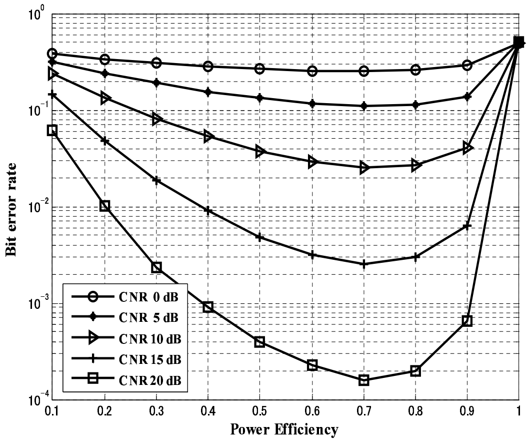
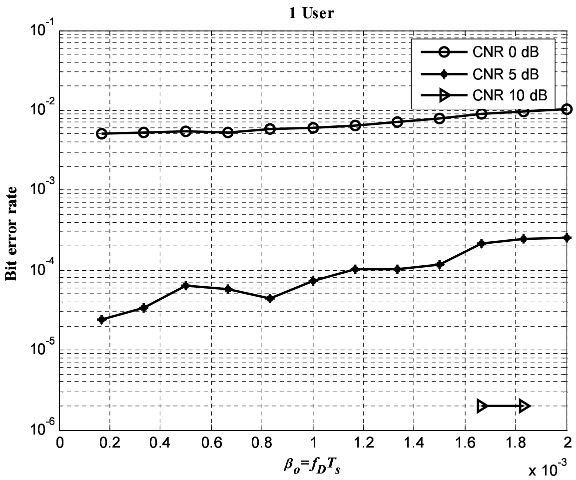
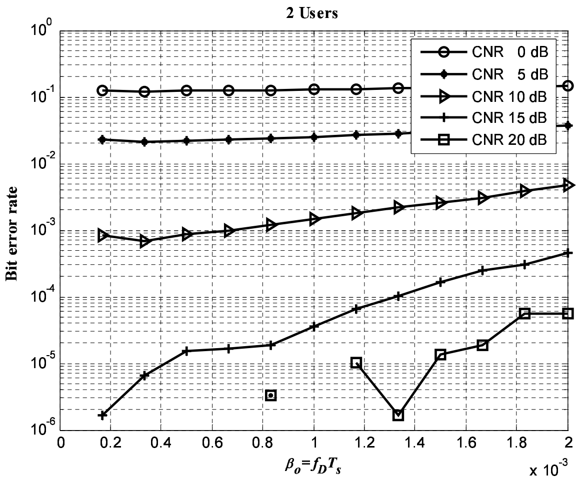


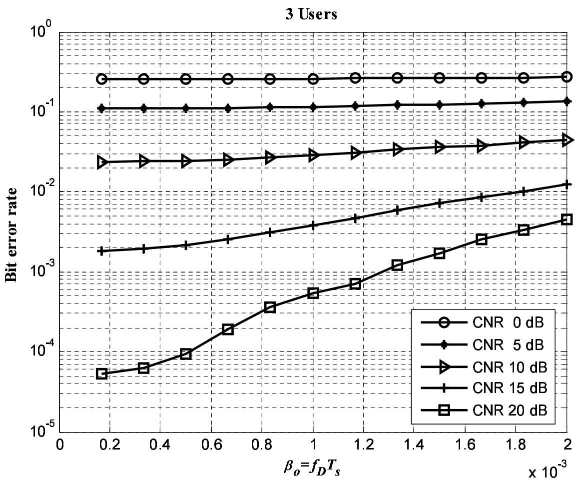
Fig. 5: BER of Power Efficency (ξ) for 3 users ($K = 3$)



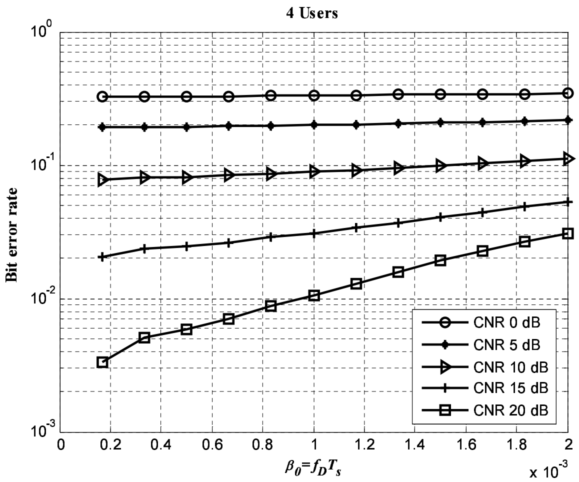
(a) 1 user ($K = 1$)



(b) 2 users ($K = 2$)



(c) 3 users ($K = 3$)



(d) 4 users ($K = 4$)

Fig. 6: BER of the proposed 2×4 MIMO STBC AA scheme in fast fading channel

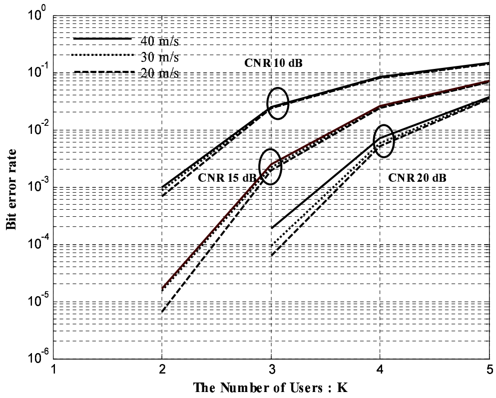


Fig. 7: BER vs the number of users in different velocity and CNR

4. Simultaion conditions

We investigate performance of MIMO STBC adaptive beamforming scheme where each of 5 users evaluated here has two transmit antennas. Carrier to Noise Ratio (CNR) is set to be 0,5,10,15 and 20 dB and bit rate of transmitting data is equal to 1 Mbps for BPSK modulation, so that symbol period T_s is 1 μsec. In the case of forgetting factor of 0.95 for RLS algorithms is adopted based on a result from computer simulation. Considered frequency f is 5 GHz so that wavelength λ is 6 cm. A mobile station is moving with different velocity from 0-120 m/s which corresponds to β_0 of $0 - 0.002$ and β_{AA} of $0 - 0.2$ as shown in TABLE 1. The suitable value of power efficiency $\xi^{(k)}$ for user k is 0.7 (=70 percentage) of total power $P_t^{(k)}$. It is clearly seen from Fig.5.

Table 2: Simulation Conditions

Carrier to Noise Ratio (CNR)	0,5,10,15 dB
Bit rate	1 Mbps
Modulation	BPSK
Velocity	0-120 m/s (0-432 km/h)
frequency (wavelength)	5 GHz (6 cm)
forgetting factor	0.95
Number of basestation antennas	4 antennas
power efficiency ξ	0.7

5. Simulation Results

In this section, we provide simulation results for the proposed scheme given in the previous section. Fig. 6 shows BER of 2×4 MIMO STBC Adaptive Array as a function of fading channel index with parameters of the number of users (K) and CNR. Figure 6 (a) is the result for one user (K=1). It is seen that CNR $\leq$ 5 dB at velocity = 30 m/s gives bit error rate more than 10^{-5}. When increasing CNR $>$ 5 dB, the scheme can absolutely suppress bit error rate.

In Fig.6 (b) for $K = 2$, the result shows that value of CNR $\leq$ 15 dB at velocity = 30 m/s gives bit error rate $\geq 10^{-5}$ while no errors occur for CNR $\geq$ 20 dB in the system.

The results of 3 and 4 users case ($K = 3$ and 4) are illustrated in Fig. 6 (c) and (d) respectively. In the case of $K = 3$, CNR $\leq$ 20 dB at velocity 30 m/s gives BER of better than 10^{-4} while $K = 4$ gives BER of more than 10^{-3}.

Figure 7 shows the result of BER as a funtion of number of users with parameter of velocity (=20,30 and 40 m/s) and CNR(=10,15 and 20 dB). It is obviously realized that in the case of up to 3 users, the system performance improves with increasing CNR but gradually reduces according to velocity expansion. It is due to co-channel interference occurred by undesired users leading to reduce system performance. Since the receive array employs $N(= 4)$ antenna elements, it can support $N-1(= 3)$ users. When the number of user exceeds 3, interferences can not be cancelled, thus causing the significant performance degradation.

6. Conclusions

In this paper we have been proposed and evaluated an adaptive beamforming for MIMO space-time block coding over fast fading Channel. The scheme, which incessantly send signal in each STBC block, can effectively suppress the signal degradation due to Doppler spread effect significantly at high frequency and high velocity. Since the receive array employs N antenna elements, it can effectively support up to $N - 1$ users to defeat co-channel interference. The research can be extended to improve system performance by optimizing modulation techniques for the future work.

References

[1] S.M.Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications”, *IEEE J. Select Areas Commun.,*,Vol. 16, No. 8, pp. 1451-1458, Oct. 1998.

[2] X.N.Tran, T. Taniguchi and Y. Karasawa, “Spatio-Temporal Equalization for Space-time Block Coded Transmission over Frequency Selective Fading Channel with Co-channel Interference”, *IEICE Trans. Fundamentals*,Vol. E88-A, No. 3, pp. 660-668, Mar. 2005.

[3] John Litva, Titus Kwok-Yeung Lo., *Digital Beamforming in Wireless Communications*, Norwood MA: Artech House, 1996.

[4] R.T. Compton., *Adaptive Antennas: Concept and Performance*, New Jersey: Prentice Hall, 1988.

[5] W.C. Jakes, Ed., *Microwave Mobile Communications*, New York: Wiley, 1974.